Chapter 2. HYPOELLIPSE Users Guide

➢ *2.1 Introduction*

HYPOELLIPSE has been developed to meet some of the research needs of the USGS and is in a constant state of modification and revision to meet new needs and implement new ideas. There are many subtle uses of the various options, and a complete description of these would expand the current work to book length. The program and manual are not error-free, and the author would greatly appreciate feedback on any errors or problems encountered.

The number of "options" available is large, and hence a new user may have trouble deciding where to begin and which options to use. The easiest course is to start out by specifying only the minimum amount of information necessary to run the program, including station locations, velocity model, and a few sets of earthquake arrival times. Then review section 2.2 for modifications to the default parameters or additional calculations required by your data set. After the run, refer to section 2.3 to interpret the printed output.

The choice of which velocity model and which variable layer thickness options to use will depend upon how much information one has about the region of study. Some of the possible choices are described below.

Very little is known about the velocity structure.

In this case a single, simple model consistent with available information could be used. The linear increase with depth over a half-space model might be chosen, in that few assumptions need to be made.

Detailed information is available about the thickness of the upper sediment-layer.

In this case, a single, simple model could be used with the thickness of the upper layer varying from station to station. VMOD of section 2.2.3.5 would be set equal to 0.0. On the STATION LIST records (section 2.2.5) the layer thickness for variable layer model 1 would be filled out for each station, and the preferred layer-thickness model for each station would be set equal to 1.

The region covered by the network includes two or more distinct velocity structures, which are well known.

In this case the multiple velocity structure option could be used. Each station would be assigned to one of the velocity models, and that model will always be used to calculate traveltimes to that station. Note that ray tracing is not done so that a shallow earthquake whose waves pass through a number of different velocity structures in the earth will be poorly modeled. However, events deeper than the velocity variations will be modeled relatively well.

Alaska data

In the case of Alaska data, three different velocity models are used, depending upon the location of the earthquake. The station delays may also be a function of earthquake location (see Chapter 7). Selection of the correct velocity model and station delay is done by the subroutine USEDLY (see 2.2.3.6), which has been set up specifically for the Alaska region. This subroutine would need to be modified for use with data from another region. These options allow all of the events from a very large area to be run in chronological order without pre-sorting by the source area.

Fault zone time delays

Work in California indicates that there is a low-velocity zone along the San Andreas Fault. To model this situation, two delays are assigned to each station, one termed delay-model 1 and the other termed delay-model 2. In addition, the stations on the east side of the fault are assigned the delay-model preference number 1, while those on the west side are assigned the number 2. The delay-model used (1 or 2) in locating a particular earthquake is determined by the delay-model preference number of the closest station to the event. For example, an earthquake near station XYZ on the west side of the fault would use delay-model 2. Delay-model 2 has fault zone delays added to the delays of stations on the east side of the fault. The reverse would be true for the earthquakes on the east side of the fault.

Poisson ratio variation between different velocity models and within one velocity model

If desired, the ratio of the P-wave velocity to the S-wave velocity (Vp/Vs) may be specified independently for each velocity model and for each model layer. A simple use of this option would be to specify a different Vp/Vs ratio for each velocity model, but constant within each model. A more complex use would be to vary the Vp/Vs ratio within each model.

➢ *2.2 Specifications for the data-input records*

The input records for this program provide three types of information:

Parameters specific to each user and required for program operation such as the four-character code and location of each station and the velocity model(s) to be used in travel-time calculations;

Parameters that control the iterative location procedure or that specify which of the available output options are to be used;

Arrival-time data to be used in the location of each earthquake.

Except where otherwise noted, items 1 and 2 above have the following format: Columns 1 through 18 contain a keyword which is scanned to determine the number and type of free format variables on the remainder of the record. The directions for each input item indicate

how many variables are required and whether they are real, integer, or character. For example,

Format: VELOCITY real, real, real

would indicate that the keyword is VELOCITY and that three real variables must be specified. All columns beginning with an ! mark are ignored, so comments may be placed on any input parameter record. Records starting with C* are processed as comments, and the contents are written to the output file. Note that the number of variables on each record must agree with the instructions, so leaving columns 19 and above blank is not equivalent to specifying a value of 0.0, but instead will generate an error message. If two records with the same keyword in columns 1 through 18 are found, the second one encountered will update the value(s) specified by the first.

Each of the input items is described below. In many cases, the parameters have default values, which are enclosed in brackets, []. If the default is desired, then the record does not need to be included in the input file. The order of sections 2.2.1 through 2.2.5 makes no difference except that the RESET TEST(1) record, which specifies the Vp/Vs ratio, must precede the VELOCITY model records (see 2.2.5).

WARNING: Do not include any tabs on the data-input records. Fortran will not read the record as expected, but the problem can be very difficult to understand, because the record will look correct when printed or viewed with a text editor.

▪ *2.2.1 Jump record - Format: JUMP character*

If a record of the form JUMP FILENAME is encountered, where JUMP begins in column 1 and the filename is in columns 6-55, then input is switched to the file 'FILENAME'. Input resumes from the original input file after an end-of-file is reached. The jump file may not include any additional JUMP records. A JUMP record may not be imbedded within the STATION LIST records or within an earthquake's PHASE records. A JUMP record after the ARRIVAL TIMES NEXT record or between the earthquakes may optionally contain in columns 56-65 the contents of the start of the next record to be processed. For example, if the columns 56-65 contain the character string '7901' followed by 6 blanks, then all of the records will be skipped until one beginning with '7901' is found. All of the records encountered prior to that one will be skipped.

▪ *2.2.2 Travel-time calculations*

Both the velocity models and the travel-time tables may be used by HYPOELLIPSE in computing travel times.

- 2.2.2.1) Velocity model specifications (Models 1-25)

    Format: VELOCITY real, real, real

The maximum number of velocity model records that can be used is given in section 1.3. There are three types of model that may be specified and up to 25 models may be defined by up to 96 records (10 models and 36 records on the PC). Models are placed in order starting with model 1. For these models a reference elevation, Eo (see Test(8) in section 2.2.4), is specified for the highest elevation in the region in kilometers above sea level. The "top" of the model is set to Eo. Earthquake depths are still computed with respect to sea level, so negative depths, up to -Eo km are allowed. Station elevations on the station records must be specified in meters above sea level. Specification of Eo allows for the correct location of earthquakes within a region of great topographic relief, such as within a volcano; travel times and take-off angles are computed correctly, even to the stations that are at a lower elevation than the hypocenter.

Constant velocity in each layer.

The three real variables to be specified are the P-phase velocity (km/s), the depth to top of layer (km), and the Vp/Vs ratio. The first record of each model must have a depth of 0.0 km specified. The model may consist of from 1 to 19 layers over a half space for the SUN version and 1 to 11 layers over a half space for the PC version. Embedded low velocity zones are allowed. For example, a 5-km thick layer with velocity of 5.2 km/s and a Vp/Vs ratio of 1.85 over a 7.0 km/s half space with a Vp/Vs ratio of 1.78 would be specified by the following two records:

VELOCITY	5.2	0.0	1.85
VELOCITY	7.0	5.0	1.78

Linear increase in velocity over a half space.

For this model the velocity increases linearly from Vo at the surface by K km/s per km until the half space is reached at a depth of D km. The velocity within the half space is Vh km/s. To use this type of model, the VELOCITY records are defined as follows:

VELOCITY	Vo	0.0	Vp/Vs
VELOCITY	K	1.0	Vp/Vs
VELOCITY	D	2.0	Vp/Vs
VELOCITY	Vh	3.0	Vp/Vs
VELOCITY	200.	4.0	Vp/Vs

Vp/Vs must be specified on each record and must remain constant.

Linear increase in velocity.

For this model the velocity begins at Vo km/s and increases at a rate of K km/s per km. To use this type of model, the VELOCITY records are defined as follows:

VELOCITY	Vo	0.0	Vp/Vs
VELOCITY	K	1.0	Vp/Vs
VELOCITY	300.	3.0	Vp/Vs

Vp/Vs must be specified on each record and must remain constant.

Example: To specify two models, the first model with 20 km of 6.0 km/s over a half space of 7.5 km/s and the second model with a linear increase with depth starting at 4.0 km/s at the surface, increasing 0.11 km/s per km of depth down to 30 km, overlying a half space with a velocity of 8.1 km/s, the following records would be used:

VELOCITY	6.0	0.0	0.0
VELOCITY	7.5	20.0	0.0
VELOCITY	4.0	0.0	0.0
VELOCITY	0.11	1.0	0.0
VELOCITY	30.0	2.0	0.0
VELOCITY	8.1	3.0	0.0
VELOCITY	200.0	4.0	0.0

A blank record between the models is optional. See the next section (2.2.2.2) for more discussion of the Vp/Vs ratio.

- 2.2.2.2) Vp/Vs ratios

The Vp/Vs ratio must be specified for each velocity layer. If specified as 0.0 then the current value on the TEST(1) will be used. Use of this feature will be described by considering various cases:

For all models to use the same Vp/Vs ratio

In this case set the TEST(1) (see 2.2.4) record to the desired value and place it ahead of the VELOCITY-model records in the program input.   Also set the Vp/Vs ratio to zero on all of the VELOCITY records.

For different models to use different Vp/Vs ratios

Specify Vp/Vs ratio on each VELOCITY model record. Do not vary Vp/Vs within a given model.

Variation in Vp/Vs ratio within a given model

This feature is allowed only for models with constant velocity layers (not for the linear-increase models). If the Vp/Vs ratio changes within a given model, then a separate S-velocity model is defined and used for the S-phase travel times. The S-phase model is assigned a number one higher than the corresponding P-phase model. For example, if two models are specified in the input stream, and the first model has a variable Vp/Vs ratio, then three models will be defined and used as follows:

	P-Phase Travel Times	S-Phase Travel Times	Vp/Vs
Stations Using Model 1	Model 1	Model 2	Variable
Stations Using Model 3	Model 3	Model 3	Fixed

In this example, no PRIMARY STATION parameter record should specify velocity model 2. (See 2.2.5)

One limitation of this feature is that the S-P interval times (see 2.2.9) do not use the S model, but instead assume the constant Vp/Vs ratio defined by the TEST(1) record. Another limitation is that each variable Vp/Vs-ratio model uses up two models, so that a maximum of 12 models with variable Vp/Vs may be specified.

- 2.2.2.3) Travel-time-table specification

These are Models 26-28 on the SUN and Models 11-13 on the PC

In addition to the 25 models previously described, up to three velocity models may be specified by travel-time tables. The first, which will be model number 26, is read from file number 21. The second and third are model numbers 27 and 28 and are read from file numbers 22 and 23, respectively. The program prompts for the names of the travel-time tables. See Chapter 6 for the operation of the program TTGEN that may be used to generate a travel-time table. This option uses portions of the code written by Klein (1985) for HYPOINVERSE. Note that the elevation of the top of the models (TEST(8), see 2.2.4) must be zero when the travel-time tables are in use.

The Vp/Vs-velocity ratio is specified for each travel-time model (see 6.5), and is used for computing S-phase travel times. However, if the specified Vp/Vs ratio is negative, then the next model will be used for computing the S-phase travel times. For example, if model 26 specifies a negative Vp/Vs ratio, then model 27 will be used for the S-phase travel times for

the stations assigned to model 26, and in this case no station may be assigned to use model 27.

- 2.2.2.4) Elevation corrections

For stations using travel-time tables, the elevation delay is computed from the station elevation (E) divided by the apparent vertical velocity within a surface layer with velocity VS. VS is specified by TEST(2) (see 2.2.4). By using apparent velocity, the elevation correction will vary from a maximum of E/VS for vertical incidence to a minimum of zero for a horizontal direct path. This formulation is reasonable for refracted ray paths but will underestimate the elevation delay for direct ray paths with non-vertical incidence at the surface.

For stations using travel-time calculations, the method above is only used to compute the elevation correction if the elevation of the top surface of the layer models is set to zero by the TEST(8) record (see 2.2.4).

If the elevation (in km above sea level) of the surface of computed travel-time models set by the TEST(8) record is not zero, then the stations with lower elevations are "embedded" within the model, while stations with higher elevations are fixed at the surface. In this case elevation corrections are not needed and the value of TEST(2) is ignored. Note that earthquakes may occur above the "embedded" stations, and that in this case travel times and angles of incidence are correctly computed. See Figures below for an example of the use of "embedded" stations.

A consequence of allowing the surface of the models to be above sea level is that earthquakes may also occur above sea level, and will in this case be given a negative depth. This depth value given on the printed output and on the summary record in columns 113-117 could then be negative.   The TEST(9) record (see 2.2.4) is used to control how the depth will be entered on columns 34-36 of the summary record. If TEST(9) is 0.0 then this field of the summary record has the same value as columns 113-117. If, however, the TEST(9) value is not equal to 0.0, then negative depths will be reported as -00 on the summary record in columns 34-36. This was done to accommodate some older software that reads the summary records but does not expect any negative depths.

The following diagrams illustrate the input parameters for the "old" and "new" ways of dealing with elevation corrections.   In the "old" system, ocean bottom stations can not be accommodated because negative depths are not allowed.   In the illustration for the "new" system, note that stations below sea level are given a negative elevation.

V=3.5   ◭ ABC 800 m wrt s.l.

Sea Level

◭ OBS -700 m wrt s.l.

V=4.0

-2000 m wrt s.l.

Halfspace V=4.5

Old system:
Station list

Name	Elevation	Station Correction
ABC	800	Positive
OBS	0	Negative

Velocity Model

Velocity	Depth to top of layer
4.0	0.0
4.5	2.0

RESET TEST 2   3.5
RESET TEST 8   0.0
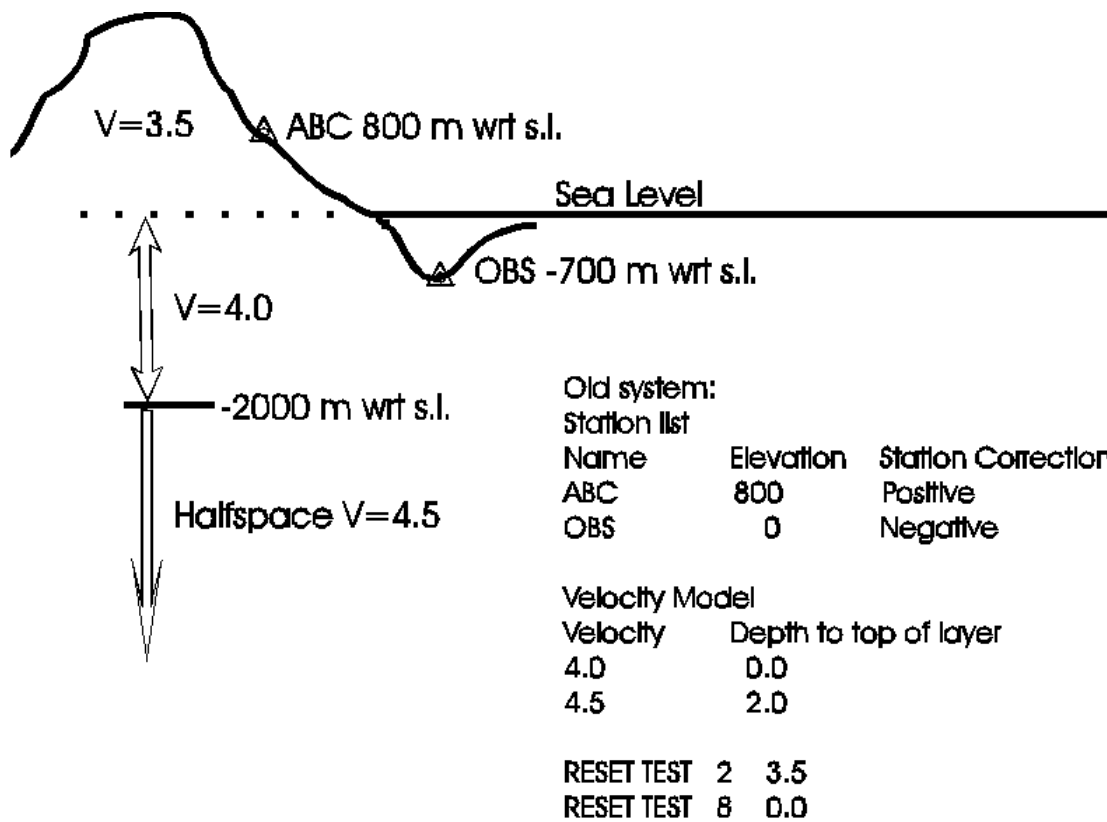
"Old" System of Accommodating Station Elevations. The velocity model is defined only below sea level and negative elevations are not allowed.

2000m wrt s.l. (top of velocity model)

V=3.5 △ ABC 800 m wrt s.l.

Sea Level

△ OBS -700 m wrt s.l.

V=4.0

-2000 m wrt s.l.

Halfspace V=4.5

New system:
Station list
Name	Elevation	Station Correction
ABC	800	None
OBS	-700	None

Velocity Model
Velocity	Depth to top of layer
3.5	0.0
4.0	2.0
4.5	4.0
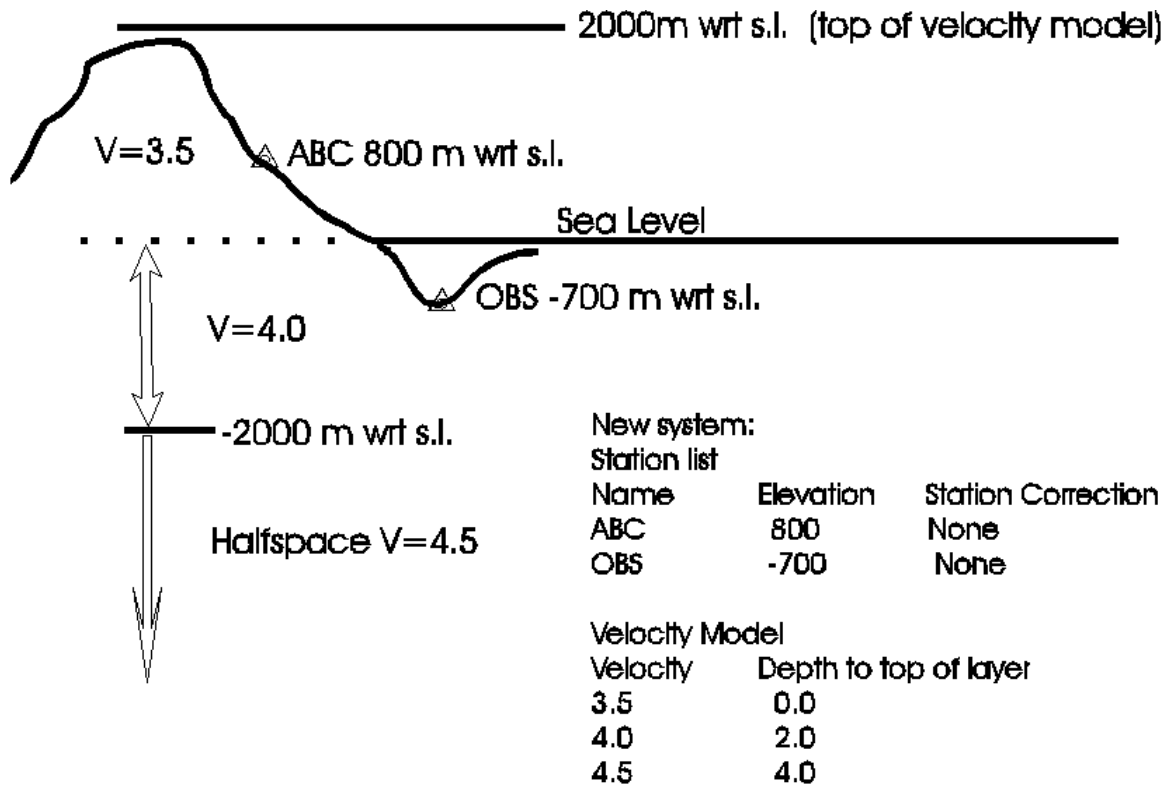
RESET TEST 2 0.0 (ignored since
                       test(8) .ne. zero)
RESET TEST 8   2.0

"New" System of Accommodating Station Elevations. The "top" of the velocity model is 2 km above sea level and negative elevations are allowed.

- *2.2.3 Option records*

This set of records is optional. Include only those required.

- 2.2.3.1) Printer option record - Format: PRINTER OPTION Integer

Code	Printed output
-2	Only warning messages.
-1	Date and time of each earthquake and warning messages.
0	Final solution for each event showing the residuals at each station.

[1]	Above plus one line per iteration. [ ] denotes default value.
2	Above plus residuals at each station for each iteration
3, 4, or 5	Above plus details from many subroutines. Used for debug purposes only.

- 2.2.3.2) Summary option record - Format: SUMMARY OPTION Integer

See 2.4.1 for the SUMMARY record format and 2.2.15 for the archive format.

Code	SUMMARY record output
0	No SUMMARY records
[1]	SUMMARY records on FILE4
2	SUMMARY records on FILE4 and ARCHIVE-PHASE FILE on FILE11
3	ARCHIVE-PHASE FILE on FILE11
4	PHASE records in input format with "fake" arrival times on FILE11 (see 2.2.13 for example of use)

- 2.2.3.3) Magnitude option record - Format: MAGNITUDE OPTION Integer

Local magnitude (XMAG) and coda magnitude (FMAG) are computed from formulas given in Chapter 4.

Code	Preferred magnitude used on the SUMMARY record and in the final output line (See 2.2.17, 1.3.5, and 2.4.1)
[0]	XMAG (Amplitude magnitude)
1	FMAG (coda length magnitude)
2	(XMAG + FMAG)/2
3	Prefer FMAG but use XMAG if FMAG is not calculated
4	Prefer XMAG but use FMAG if XMAG is not calculated

(Add ten to the code for median rather than the average value to be used as the preferred magnitude.)

The MAGTYP in column 80 of the SUMMARY record is set to X, F, or A, (corresponding to XMAG, FMAG, and average) to denote which type of magnitude was used. If no location can be obtained, then the magnitude is left blank and MAGTYP is set to K.

If the code is negative, the calculation will be based on the F minus S (F - S) rather than the F minus P (F - P) time. F - P is still entered on the ARRIVAL TIME records as the coda length, but the S-P interval is subtracted. If S has not been read, the S residual is greater than (F - P)/10., or the computed S weight is zero, then the calculated rather than the observed S-P interval is subtracted. See 2.2.17 for the use of magnitudes computed outside of HYPOELLIPSE.

- 2.2.3.4) Tabulation option record - Format: TABULATION OPTION Integer

The tabulation at the very end of each run gives various statistics such as the average residual for each station.

Code	Events included in the final tabulation
0	No tabulation
+1	Tabulation for A quality only
[+2]	Tabulation for A and B quality
-2	Tabulation for A and B quality
+3	Tabulation for A, B, and C quality
+4	Tabulation for A, B, C, and D quality

Positive for quality based on error ellipsoid.
Negative for quality defined in HYPO71 (Lee and Lahr, 1972).
See 2.3.5 for definition of A, B, C, and D.

- 2.2.3.5) Variable-layer option record

Format:

VARIABLE LAYER	Integer	Integer	Integer
	NLAY	VMOD	LOWV

This record is required for the variable-layer-thickness option. NLAY is the number of the layer to be varied, VMOD determines how the layer-thickness model is chosen, and LOWV is set to 1 if an equal and opposite change in the thickness of the layer below the variable layer is to be made.

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For each station two thicknesses are specified for the variable layer, a model 1 thickness and a model 2 thickness. In the calculation of each travel-time two stations are considered, the closest station to the epicenter and the receiving station. VMOD is used to specify which of three options is desired:

VMOD	Usage
+1	The thickness specified for the receiving station's preferred model (1 or 2) is used. For example, the station STA has the layer thickness for variable-layer model 1 equal to 3 km, and model 1 is its preferred layer-thickness model. Then all of the travel times to station STA will use 3 km as the variable-layer thickness. With this option only one thickness needs be specified for each station.
0	The depth to the lower boundary of the variable layer is calculated for the receiving and for the closest station. If the hypocentral depth is below the average of the two lower-boundary depths, then the receiving station's variable-layer thickness is used. For shallower depths, the lower-boundary depth is set to the average of the receiving station's and closest station's lower- boundary depths.
-1	The thickness model (1 or 2) preferred by the closest station to the epicenter is used to determine the variable-layer thickness used at each station

Example of variable-layer-model velocity in the case where the first-layer thickness is variable and LOWV equals 1:

VELOCITY STRUCTURE AS SPECIFIED ON CRUSTAL STRUCTURE RECORDS

    Depth 0 – Top of 5 km/s layer
    Depth 10 – Top of 6 km/s layer
    Depth 15 – Top of 7 km/s layer

VELOCITY STRUCTURE WHEN VARIABLE LAYER (1) THICKNESS EQUALS 5 KM

    Depth 0 – Top of 5 km/s layer
    Depth 5 – Top of 6 km/s layer
    Depth 15 – Top of 7 km/s layer

Note that in this example no station should be given a variable-layer thickness greater than 15 km.

- 2.2.3.6) Delay model, velocity model, and starting depth option record

Format: SELECT DELAY Integer-code

If the code is positive, which is the default, the delay-model used (1-9) is the one preferred by the closest station. If the code is less than or equal to zero, then the subroutine USEDLY is used to control the delays, velocity model and starting depth of each event. Subroutine USEDLY, as distributed, has been tailored for use in processing data from Alaska, and would need to be modified for another region. The current, Alaska, algorithm in USEDLY, which is used when the code is negative, does the following:

Reads the first record following the SELECT DELAY record for the name of a file defining the cylindrical-delay regions.

Selects a velocity model to match earthquake location.   Northern model if north of 62.5°N, southern model if south of 62.5°N unless within a cylindrical region or within the Gulf of Alaska. The velocity model is updated before each iteration, but not after the iteration defined by TEST(37).

The delay model is set to one unless the earthquake location is within a cylindrical-delay region or within the Gulf of Alaska. The Gulf uses delay model 5 and delay models 2, 3, and 4 are assigned to cylinders. Up to 10 delay-models may be specified. The delay-model selection is updated each iteration, but not after TEST(37). Chapter 7 describes the use of cylindrical regions in more detail.

Sets an upper limit on the maximum starting depth depending on each event's starting location. Section 2.2.12 summarizes how the first trial depth is determined.

For events in the Gulf of Alaska, fixes depth at 10 km.

- 2.2.3.7) Missing stations option record - Format: MISSING STATIONS Integer-code

Code	Effect
0	The station list will be searched after each event is located for stations that would possibly improve the earthquake solution quality. Stations are listed which are closer to the epicenter than the third-closest station used to compute the solution or that would reduce the GAP (see 2.3.6) by 30° or more.
[1]	A search for "missing" stations is not conducted.

Searching for missing stations requires that the entire station list be initialized, so this option can not be used with a negative code on the BEGIN STATION LIST record. (See 2.2.5)

- 2.2.3.8) Sort option record - Format: SORT OPTION Integer-code

Code	Effect
[0]	Stations are listed in the output in order of increasing epicentral distance.
1	Stations are listed in the same order as the input ARRIVAL TIME records.

- 2.2.3.9) Compress option record - Format: COMPRESS OPTION Integer-code

Code	Effect
0	Printout is compressed by not skipping to the top of a new page for each solution.
[1]	Printout for each earthquake starts on a new page.

- 2.2.3.10) Debug option record - Format: DEBUG OPTION Integer-code

Code	Effect
[0]	This option is not called into play and no additional record is needed.
1	This option is used and the record below must be included:

Debug limits record - the following format must be used:

(10X, F5.2, 5X, F5.2, 5X, F5.2, 5X, i5, 5X, i5, 5X, i5)

For example:

1-10	11-15	16-20	21-15	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65
Max RMS	0.65	PRES	1.00	SRES	1.00	NWOUT	2	NMAX	8	SEMX	25

The words are typed only for your convenience and the order of the variables is fixed. The value of any variable that is not specified will be read as zero. This setup would give a detailed printout of travel times, residuals, etc., for each station only for "Debug events" defined by:

RMS > MAX RMS, 0.65 s, or
Largest P-Res with computed weight greater than 0.2 > PRES = 1 s, or

Largest S-Res with computed weight greater than 0.2 > SRES = 1 s, or
Combined number of P and S readings weighted out by the program > NWOUT = 2, or
(this excludes readings assigned weight-codes 4-8)
Total number of iterations > NMAX = 8, or
The maximum error estimate > SEMX = 25 km.

The DEBUG OPTION can be used with the COMPRESS OPTION so that each event will not start on a new page.

TABLE OF DEBUG OPTIONS		
CODE	EVENT PRINTOUT	SUMMARY RECORD
[0]	Controlled by PRINT OPTION.	Controlled by SUMMARY OPTION
+1	Summary line for good events. Detailed for debug events.	For both good and debug events
-1	Same as for +1	Only for good events
+2	No print for good events. Detailed for debug events.	For both good and debug events
±3	Detailed for all events To rerun debug events with only critical stations set TEST(44) = 1.0	For both good and debug events

- 2.2.3.11) Find the global minimum in depth - Format: GLOBAL OPTION Integer

This option is now set up to find the best solution in regions where the depths vary from the surface to 100 km or more. This option can not be used if the hypocenter is fixed on a plane, so TEST(47) (see 2.2.4) must be set to 0.0. Also, a global solution will not be attempted if the instruction record fixed location indicator is set for fixed depth (1) or fixed hypocenter (7 or 9).

TABLE OF GLOBAL OPTIONS	
Code	Effect
[1]	GLOBAL OPTION is turned off.

0	Global search option is turned on. The "global" search begins by solving two fixed-depth solutions: S(1) with the event at the Earth's surface (z = - TEST(8)) and S(2) with z first fixed at DEEPZ = TEST(42) km below sea level and then allowed to go free.

If the depth of S(2) is within 0.1 km of the surface, the surface solution is reported.

If the depth of S(2) is less than CUTZ = TEST(27) km below sea level and

➤ the surface RMS is significantly lower than RMS of S(2) then a free depth solution starting at S(1) is reported.

➤ the RMS of S(2) is significantly less than the surface RMS, then S(2) is reported.

➤ neither solution has significantly lower RMS, so the one with lower RMS is reported and the printer output file will give the RMS and depth of both solutions.

If the depth of S(2) is greater than or equal CUTZ = TEST(27) below sea level then a solution S(3) with z fixed at SHALZ = (CUTZ - TEST(8))/2.0 km below sea level is computed.

➤ If the RMS of the surface solution S(1) is less than the RMS of S(3) then find a free-depth solution called S(4) starting at S(1).

▪ If the difference in depth between S(3) and S(4) is less than DEEPZ/10.0 then use S(4) as the reported solution.

▪ If the solutions S(3) and S(4) are more than DEEPZ/10.0 km apart, then

  if S(4) has significantly lower RMS value it is reported as the final solution.

  if S(4) does not have significantly lower RMS than S(3), both are reported to the printed output, and S(4) is taken as the final solution.

➤ If the RMS of the surface solution S(1) is greater than the RMS of S(3) then find a free-depth solution called S(4) starting at S(3).

▪ If the difference in depth between S(1) and S(4) is less than DEEPZ/10.0 then use S(4) as the reported solution.

▪ If the solutions S(1) and S(4) are more than DEEPZ/10.0 km apart, then

  if S(4) has significantly lower RMS value it is reported as the final |

	solution.
	if S(4) does not have significantly lower RMS than S(1), both are reported to the printed output, and S(4) is taken as the final solution.

The error limits reported to the output and to the SUMMARY record are the greatest deviations of depth with RMS less than RMSLIM (See Chapter 3.2 for the definition of RMSLIM), even if there are intervening peaks in the RMS. This limit is approximately equivalent to one standard deviation in depth.

For different networks and regions, the values of DEEPZ and CUTZ may need to be adjusted for best results.

- 2.2.3.12) Residual option record - Format: RESIDUAL OPTION Integer

After the initial location of an earthquake, the printed output can be checked for large residuals. When the original seismograms are reviewed to correct errors, inexperienced processors can be influenced in their revisions by the printed computer residual. Printing the calculated value of the residual may be hazardous and ***not*** recommended because, in many cases, the true error, if any, is not reflected by the individual residuals.

To prevent this ill-advised feedback, the "preliminary option" may be used.

TABLE OF RESIDUAL OPTIONS	
Code	Effect
0	Prints station residual in "residual" format, as described below.
[1]	Prints station residual in normal format.

The "residual" format consists of the following:

P and S residuals less than 2.25 s are shown only in absolute value and are rounded to the nearest 0.5 s. The printed residual (Rp) is related to the absolute value of the calculated residual (R) as follows:

$0 < R \leq .25$	$Rp = 0$
$0.25 < R \leq .75$	$Rp = 0.5$
$0.75 < R \leq 1.25$	$Rp = 1.0$
$1.25 < R \leq 1.75$	$Rp = 1.5$
$1.75 < R \leq 2.25$	$Rp = 2.0$

Large residuals are flagged. For residuals (R) that have not been weighted out automatically by the program, an * is placed after the residual if it meets one of the following criteria:

P Residuals

➢ R > 0.6 for one of the closest five stations
   R > 0.9 for distance less than 150 km
   R > 1.5 for epicentral distance less than 350 km

S Residuals

➢ R > 0.9 for one of the closest five stations
   R > 1.5 for epicentral distance less than 150 km
   R > 2.0 for epicentral distance less than 350 km

- 2.2.3.13) Weight assignment option

Format: WEIGHT OPTION Real Real Real

The relative weight assigned to each reading is dependent upon an integer weight-code, which can range from 0 for the most impulsive to 4 for readings that are too uncertain to be used in the hypocentral solution. It is recommended that TEST(29) (see 2.2.4) be set to minus the standard error of the best readings, and that these readings be assigned zero weight-code. Less certain readings are then assigned larger weight-codes. If, for example, weight-codes of 1, 2, and 3 are to be assigned to readings that have standard errors that are 5, 10, and 20 times less certain than the best, respectively, then the three WEIGHT OPTION parameters should be set to 5, 10, and 20. For processing Alaska seismic data, 0, 1, 2, and 3 weight-codes are assigned to readings with standard errors ranging up to 0.1, 0.5, 1.0, and 2.0 s, respectively.

The graph below is used to assign weight-codes according to these limits.

```
            Picked Arrival
          ↙   Time
              ▲
              ║   0        W
              ╱╲           E
             ╱  ╲          I
            ╱    ╲ 1       G
           ╱      ╲        H
          ╱        ╲       T
         ╱          ╲  2   
        ╱            ╲     C
       ╱              ╲    O
      ╱                ╲   D
     ╱                  ╲  E
    ╱          3         ╲ 
   ╱                      ╲
  ╱_____╲

   ├──┼──┼──┼──┤
   2  1  0  1  2
```
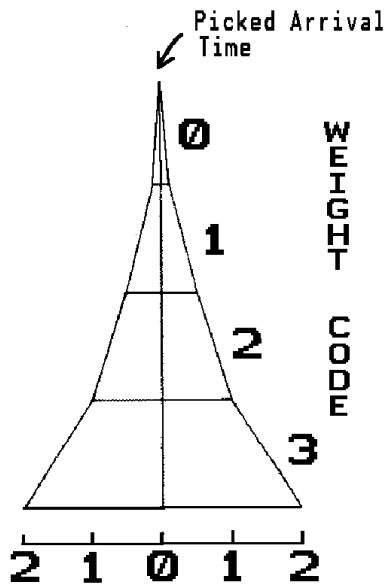
Reading Uncertainty (s)

The default weight and corresponding relative standard error corresponding to each weight-code is given in the table below:

WEIGHT-CODE	STANDARD ERROR (S)	STANDARD ERROR RELATIVE TO READINGS WITH WEIGHT-CODE ZERO	COMPUTED WEIGHT
0	0.1	1.0	1.0
1	0.5	5.0	1/25
2	1.0	10.0	1/100
3	2.0	20.0	1/400
4	INFINITE	INFINITE	0.0

To change the default weight assignments, include a record with WEIGHT OPTION starting

in Column 1 followed by the relative standard errors for weight-codes of 1, 2, and 3. For example, the default weights that used to be set in older versions of HYPOELLIPSE could be reset with:

WEIGHT OPTION   1. 33   2. 4.

- 2.2.3.14) Ignore summary records - Format: IGNORE SUMMARY REC Integer-code

Code	Effect
[1]	The starting location parameters (latitude, longitude, depth, and origin time) may be taken from the SUMMARY record. (see 2.2.12)
0	The SUMMARY record will be ignored in determining the starting location parameters.

- 2.2.3.15) Header content record - Format: HEADER OPTION Any alphanumeric heading

Used to write a heading of up to 50 characters above each earthquake in the output.

- 2.2.3.16) Comment records - Format: C* Any Comment

Any record with C* in columns 1-2 will be printed out during program execution but is otherwise ignored. Comments may not be imbedded within the station list.

- 2.2.3.17) Relocate after revising the delays - Format: RELOCATE Integer-code

This will cause the input file to be rewound and rerun N = Code times. Prior to each rerun, the station delays for delay-model 1 will be revised by adding the event-weighted, average station residual. At the end of the job a file is generated on Unit 13 with one record for each station used. These records are in the format of the primary station records. (see 2.2.5) The P- and S-delay field for delay-model 1 will contain the revised station delays. The field for delay-models 2 through 5 will be blank. The default is Code = 0.

- 2.2.3.18) Uofacal option - Format: UOFACAL OPTION Filename

Used to specify the name of the file that contains calibration data in the format used by the UAGI. (see 4.2.3). Type UOFACAL beginning in column 1 and the filename in columns 19-68.

- 2.2.3.19) Reset all control parameters to the initial default values

Format: STANDARD TEST

- 2.2.3.20) Constants noprint option - Format: CONSTANTS NOPRINT Integer

Controls whether the station list, the user-specified constants, and the control options will be written to the output file.

Code	Effect
0	Do not write out these items.
[1]	Write out these items.

- 2.2.3.21) Blank source option - Format: BLANK SOURCE One-Character Code

The station list may contain calibration, polarity, and telemetry-delay information for various sources of data. The arrival-time records have columns to specify the source of the P- and S-arrival times, the first motion, and the amplitude. However, some sets of arrival-time data may not have any source code entries. The BLANK SOURCE code specified on this record will be used whenever the arrival-time source code is blank in computing delays, magnitudes and corrected polarities.

- *2.2.4 Reset test records - Format: RESET TEST Integer Real*

These records have RESET TEST typed starting in column 1 and beginning in column 19 the test number and the new value for the test variable. All of these records are optional and need be included only if a non-default value is required.

Test No.	Default Test Value	Description
1	1.78	Ratio of P-wave to S-wave velocity
2	5.0	P-phase velocity for elevation corrections (km/s). If the value is negative, make no elevation corrections. If zero, use first-layer velocity for elevation corrections. If greater than zero, use this for elevation corrections. In the latter case, value must be less than first layer P-phase velocity. Used with computed models if TEST(8) = 0 and with travel-time tables.

		Trial Location
3	0.0	First trial latitude (degrees). North positive. If TEST(3) or (4) = 0, then ignore. See 2.2.12 for use.
4	0.0	First trial longitude (degrees). West positive. If TEST(3) or (4) = 0, then ignore. See 2.2.12 for use.
5	-99.0	Used for first trial depth (km with respect to sea level) unless equal -99 or unless Global Option is in effect. See 2.2.12 for use.
6	0.0	RMS may optionally be computed at additional points on a sphere surrounding the final hypocenter. This is the radius of the sphere (km). If zero, no auxiliary RMS values are calculated. If negative, and if one or more points have lower RMS than the final solution, continue iteration once starting at point with lowest RMS value.
7	10.0	Focal Mechanism Plot. Minimum number of first motions for a first-motion plot to be made. If negative, make a second plot showing station codes.
8	0.0	Elevation of top of computed models with respect to sea level (km).
9	0.0	If not zero, reset negative depths in summary record cols. 32-36 to -00. True depth below (positive) or above (negative) sea level always given in cols. 113-117 of the summary record..
		Distance Weighting
10	0.0	Apply distance weighting on this iteration. See also TEST(11) and (12).
11	50.0	XNEAR = Greatest distance (km) with assigned weight multiplied by 1.0
12	100.0	XFAR = Least distance (km) with assigned weight of multiplied by 0.0. See also TEST(46).
13	50.0	Azimuthal Weighting. Apply azimuthal weighting on this iteration. Warning: this option has not been tested.

Truncation Weighting		
14	50.0	If there are 6 or more phases, then weight out large residuals on this iteration. See also TEST(15).
15	10.0	Give zero weight to residuals greater than this (s).
Boxcar Weighting		
16	50.0	If there are 6 or more phases, then apply boxcar weighting on this iteration. See also TEST(17), (34) and (35).
17	2.0	Give zero weight to residuals greater than this times the standard deviation (s).
Jeffrey's Weighting		
18	50.0	Begin Jeffrey's weighting on this iteration. (See also TEST(34) and (35)).
19	0.05	Use Jeffrey's weighting only if RMS is greater than this (s).
20	0.05	Mu of Jeffrey's weighting function

Test No.	Default Test Value	Description
21	9.0	Maximum number of iterations allowed
22	35.0	Limit change in focal depth to approximately this amount (km).
23	0.7	If move would take earthquake above surface, move this proportion of the way to the surface
24	35.0	Limit change in epicenter to approximately this amount (km).
25	40.0	Fix depth if epicentral change greater than this (km).
26	0.0025	Stop iterations if adjustment squared is less than this (km).
27	20.0	Global solution option: if deep solution converges below this

		depth with respect to sea level, continue at a depth half way between this depth and the surface of the velocity models. See also TEST(42).
28	0.0	To fix the hypocenter on a plane, set absolute value of this equal to azimuth of plunge line of plane (0° to 360° measured clockwise from North). If negative, then a free solution will be determined starting at the best location on the plane. See also TEST(30) and TEST(47).
29	-0.1	If TEST(29) is positive, the standard error of readings assigned zero weight-code is set equal to the RMS residual, unless there are zero degrees-of-freedom or the estimated reading standard error falls below TEST(29). In that case TEST(29) is used for the standard error of the readings. If TEST(29) is negative, the standard error of the zero weight-code readings is always set equal to minus TEST(29). See also 2.2.3.13.
30	0.0	Used if TEST(28) is positive, causing solution to be fixed on a plane. If positive, this is dip of plunge vector of the plane. See also TEST(28) and TEST(47). If negative, then fix epicenter and solve only for depth and origin time, ignoring TEST(47).
Duration Magnitude Parameters (See also TEST(40) and (43))		
31	-1.15	C1, constant
32	2.0	C2, *log((F-P) * FMGC)
33	0.0	C3, *DELTA
34	0.0	If not equal 0, scale the normal equations.
35	0.001	Minimum damping of normal equations.
36	100.0	Maximum first trial depth (km), if computed from P-arrival times.
37	3.0	If termination occurs before this iteration, set iteration number to this and continue. Prevents iteration from stopping before all forms of weighting have been applied. After this iteration, velocity and delay models will not be changed by the SELECT DELAY (2.2.3.6) option.

38	0.0	If 0, use of S arrivals depends upon S-data indicator on INSTRUCTION record. If 1, locate all with and without S arrivals. If 2 locate all with S arrivals. If 3, locate all without S arrivals. If 4, fix all solutions at starting hypocenter, and use S arrival. If negative, use S arrivals only to fix origin time.
39	1.0	Multiply the S and S-P weight-code weights by this factor.

Test No.	Default Test Value	Description
40	0.007	Duration magnitude parameter C4; multiplies the DEPTH (see also TEST(31)-(33) and TEST(43))
41	0.0	If this equals 1, PRINT OPTION is greater than or equal 1, and SUMMARY OPTION equals plus or minus 1, then write a new SUMMARY record after each iteration.
42	75.0	Global solution option: deep starting depth (km with respect to sea level). See also TEST(27).
43	0.0	Duration magnitude parameter C5; multiplies (log ((F-P) *FMGC)**2) (see also TEST(31)-(33) and TEST(40))
44	0.0	If 1, rerun "debug events" again (See 2.2.3.10) with critical stations; if 2, make a second run for all events with critical stations See note below for definition of critical stations.
45	0.1379	X-scale factor for focal mechanism plots. Adjust for printer in use. (See 2.3.9)
46	0.0	If TEST(46) not equal 0.0, distance-weighting constant XFAR (see TEST(12)) will be set to a minimum of 10 km beyond the distance of the TEST(46)th station. If TEST(46) is negative, then any station beyond XFAR that would reduce a gap greater than 60° by 30° or more is given a distance weight of 0.5.

47	0.0	Constraint equation weight for hypocenter fixed on plane. A large value, such as 1000, will prevent out-of-plane movement. If equal to 0, this option is not used. See also TEST(28) and (30). This option may not be used with the GLOBAL OPTION (see 2.2.3.11).
48	6.5	Half-space velocity used for first trial location (km/s).
49	0.0	If absolute value equals 1, compute Vp/Vs and origin time; if equals 2, also make printer plot of S-P vs P. If negative, use this origin time for earthquake location.
50	0.0	Compute this number of fixed depth solutions, starting with $Z(1) = -TEST(8)$ and continuing with $Z(i+1) = 1.2*Z(i) + 1.0$. The maximum this value can be is 22., which produces a maximum depth of 225 km.
51	1000.0	Beyond this epicentral distance use first travel-time table model.
52	2800.0	Wood-Anderson magnification used in XMAG calculations.
53	1.0	If equal to 1, then assume stations with 4-letter codes ending with e or n are horizontal east-west and north-south stations, respectively.
54	200.0	If 1st computed trial epicenter is greater than this from closest station, start location at closest station.
55	19.0	Default century if not specified on the summary record.

Note on TEST(44) - critical stations

In an effort to speed up the identification of reading errors during preliminary runs of data, an option to automatically rerun each event using only the most important arrivals was developed. In some cases comparing the solution using only critical stations with the normal solution can identify reading errors. In the printed output for critical-station reruns, readings that are not used are marked with an 'X' between the residual and the weight. Critical stations are defined to be:

The closest four stations with P-phase readings that have weight codes less than 4;
b) Additional stations with P- or S-phase readings are considered one at a time and are added only if they reduce a gap of greater than 72° by 5° or more;
c) S arrivals are used when available at "critical" stations. If no S arrival is available from a

critical station, then S is used from the closest non-critical station with a weight code less than 4.

- § *2.2.5 Station list*

The station list is set up so that a complex history of station changes can be maintained, such as the opening and closing dates and changes in gain and polarity (see discussion in 2.2.7). For the southern Alaska seismic network, a complex history beginning in 1971 has been developed. However, in situations where this information is not needed, the station list may consist of just two entries for each station, with many of the fields left blank. Comment records that begin with C* in columns 1 and 2 may be included within the station list.

- • 2.2.5.1) Begin station list - Format: BEGIN STATION LIST Integer-code Integer-date

The first record has BEGIN STATION LIST typed in columns 1-18, followed by code and date of the first event to be run. The date includes year, month, and day (for example: 19921028). If the station list contains many stations that expired before the time of the first event, specifying the correct starting date will eliminate the expired stations from the initial printed station list. The STATION records follow this record. (Note that in this Y2K version the date must include the century.)

CODE	Meaning
0 or 1	Print station list updated to date specified and print new station parameters during run as changes occur.
-1	Do not print station list or print new station parameters when a station is updated during run.

- • 2.2.5.2) Primary station parameters - Formatted as indicated below.

For each station there is one entry with PRIMARY STATION PARAMETERS, such as latitude and longitude, and one or more entries with TIME-DEPENDENT STATION PARAMETERS, including calibration parameters and polarity indicator. To speed up the search for station parameters, the current version of HYPOELLIPSE requires the station list to be in alphabetical order according to the extended 5-character station code. Right justifying the station code and concatenating the component (z, n, or e) forms this extended name. The station list must be arranged so that those stations with 1-character codes precede those with 2-character codes, which perched those with 3-letter codes, which preceded those with 4-character codes.

Alphabetical order is not required if the alternate version of subroutine PHAIDX, which is included in with the source code, is used. In either case, the first station should be near the

center of the network, as it is used as a reference location for calculating the azimuth of approach of a plane wave. A fake station with the code AAA can be used as the first station. See 1.3 for the maximum of number of stations allowed.

Format for PRIMARY STATION PARAMETER records:

Item	Column Nos.		Format
Station Code	1	4	A4
Latitude (Degrees)	5	6	i2
N or blank for North, S for South		7	A1
Latitude (Minutes)	8	12	F5.3
Longitude (Degrees)	14	16	i3
W or blank for West, E for East		17	A1
Longitude (Minutes)	18	22	F5.3

THE FOLLOWING ITEMS ARE OPTIONAL, AND IF LEFT BLANK THE DEFAULT VALUES WILL BE USED.

Item	Default Value	Column Nos.		Format
Elevation (Meters)	0	23	27	i5
Preferred velocity model (SUN: models 1-25 computed, 26-28 from tt table) (PC: models1-10 computed, 11-13 from tt table)	1	28	29	i2
Preferred layer thickness model (1-2)	1		30	i1
Layer thickness for model 1	0.0	31	34	F4.2
Layer thickness for model 2	0.0	35	38	F4.2
Preferred delay-model (1-9)	1		39	i1
P-delay for model 1	0.0	40	43	F4.2
S-delay for model 1	0.0	44	47	F4.2

P-delay for model 2	0.0	48	51	F4.2
S-delay for model 2	0.0	52	55	F4.2
P-delay for model 3	0.0	56	59	F4.2
S-delay for model 3	0.0	60	63	F4.2
P-delay for model 4	0.0	64	67	F4.2
S-delay for model 4	0.0	68	71	F4.2
P-delay for model 5	0.0	72	75	F4.2
S-delay for model 5	0.0	76	79	F4.2
*Component, Blank or Z, N, or E for Vertical, North-South and East-West component stations.	Z		80	A1

*Extended, 5-character, station codes are formed from the station code given in columns 1-4 (shifted to the right) plus the component from column 80. If the component is blank, z is assumed. This 5-character name must agree with the name on the arrival-time record (see 2.2.6.2).

NOTE ON DELAYS: The total delay used for the S-phase is just the S-delay given on the STATION record. [Some earlier versions of HYPOELLIPSE added a term to the S-delay equal to (Vp/Vs ratio)*(P-delay).]

- 2.2.5.3) Time-dependent station parameters

Format for TIME-DEPENDENT STATION PARAMETER records:

Item	Default Value	Column Nos.		Format
Station code		1	4	A4
*			5	A1
If any of the following items are left blank, default values will be used.				
Station weight (Multiplies the weight derived from weight-code. (see 2.2.6.)	1.0	6	9	F4.2
Primary system response code:	1	10	11	i2
0 = for Wood-Anderson 1= USGS Central California Network Standard 2 = EV-17 and Develco 3 = EV-17 and Teledyne 4 = HS-10 and Develco 5 = L-4C and Develco 6 = L-4C and Teledyne 7 = L-4C replacing HS-10 and Develco 8 = Ten-day Recorders 9-17 = User specified calibration curve (See 2.2.10 and Chapter 4) 18 = Use UAGI magnitude calculation (See 4.2.3)				
A1VCO 5-Hz Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)		12	15	F4.0
XMAG calibration constant-C10 (See 4.2.2.2)	0.0	16	20	F5.2
XMAG correction (added to amplitude magnitude) NOTE: If the number typed is the actual magnitude correction plus 10, the magnitude for this station will be computed and listed but not used in computing the average event magnitude. For example, if XMAG correction = 10.2, a correction of +0.2 is applied to all XMAG's for this	0.0	21	24	F4.2

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station, but none are used in the average magnitude computed for each event.				
XMAGWT magnitude weight (If zero, exclude XMAG's from this station from event mean and median XMAG magnitude calculations. Print "e" next to XMAG value in output.	1		25	i1
FMAGWT magnitude weight (If zero, exclude FMAG's from this station from event mean and median FMAG magnitude calculations. Print "e" next to FMAG value in output.	1		27	i1
FMAG correction (Multiplies the observed coda).	1.0	28	31	F4.2
P-weight-code replacement. For this station, an ARRIVAL TIME record with P-weight-code of 0, 1, 2, or 3 will be replaced by this code. If blank, use assigned weight.	none		32	i1
S-weight-code replacement. For this station an ARRIVAL TIME record with an S-weight-code of 0, 1, 2, or 3 will be replaced by this code. If blank, use assigned weight.	none		33	i1
Field gain setting (Not used by HYPOELLIPSE).	0	35	36	i2
Palmer attenuator setting of 0, 1, or 2. (Not used by HYPOELLIPSE.)	0		37	i1
Year, month, and day (e.g. 19891231).	99999999	38	45	i8
Hour of expiration of information in these entries. If another entry with revised time dependent parameters does not follow, then this is time of station expiration.	0	46	47	i4

Two telemetry delays are specified. The primary delay is used unless (1) the source of data is one of those specified for the alternate delay or (2) the source code is "T" or "N", both of which have already been corrected. Certain source codes are equivalent for the purposes of the telemetry delays. For example, the USGS film viewer (source code "V") is equivalent to the USGS one-film digitizer (source code "1"). A complete list of source codes is given in section 4.2.2.2. The following table shows delay-equivalent codes. Only one code from a set of equivalents need be included as an alternate delay code.

Source of data	Equivalent codes
USGS Film	V, *, 1, 4
USGS Tape	S, E, 2
UAGI Film	%, A, F
UAGI Masscomp or SUN Computers	D, J, X,
USGS./UAGI PC's	P, O, U, I, G, K

Primary telemetry time correction	0.0	48	51	F4.2
Source codes of arrival times that will use the alternate telemetry time correction		52	55	4A1
Alternate telemetry time correction	0.0	56	59	F4.2

Polarity indicators may be any of the following:

Indicator	Meaning	Focal Mechanism Symbol:
N	Normal	Same as phase record
R	Reversed	Reverse of phase record
+	Probably normal	Same as phase record
-	Probably reversed	Same as phase record
?	Unknown	Question Mark

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Five date-source indicators may be specified, one for each of the following sources of Alaska data:

Item	Default Value	Column Nos.		Format
Source of data				
USGS Film	Source codes effected			
USGS Tape or USGS/UAGI PC's	V, *, 1, 4		60	A1
ATWC Film	S, E, 2, P, O, U, I, G, K		61	A1
UAGI Film	W		62	A1
UAGI Computers	%, A, F		63	A1
Other sources	D, J, X		64	A1
	any other code, including blank		65	A1

The following items allow amplitude measurements for a given station to be made on up to four additional recording systems, each with a different frequency response:

Item			Format
System response code	72	73	i2
A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	74	77	F4.0
XMAG Calibration constant-C10	78	82	F5.2
System response code	84	85	i2
A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	86	89	F4.0
XMAG Calibration constant-C10	90	94	F5.2
System response code	96	97	i2

A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	98	101	F4.0
XMAG Calibration constant-C10	102	106	F5.2
System response code	108	109	i2
A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	110	113	F4.0
Calibration constant-C10	114	118	F5.2
If station has been moved a small distance, these are the new coordinates:			
New minutes of latitude	119	123	F5.3
New minutes of longitude	124	128	F5.3
New elevation	129	132	i4

- 2.2.5.4) End station list - Format: END STATION LIST

A record with END typed starting in column 1 follows the last STATION record. The record immediately following the BEGIN STATION LIST record may be of the form JUMP FILENAME, where the STATION records are contained in the file 'FILENAME'. In this case, no END record is used in either the original input file or the jump file.

- 2.2.5.5) Additional delays

Delays may be specified for 5 additional models (numbers 6-10). Each set of additional delays begins with a record with DELAY typed in columns 1-5 and an integer delay-model number (6-10) beginning after column 18. This record is followed by a set of records with station code in columns 1-4, followed by P Delay and S Delay (s) in free format. After the last station, a record with END starting in column 1 ends the set of delays. The stations need not be in alphabetical order, and stations not included will be given delays of zero.

- *2.2.6 Arrival times*

- 2.2.6.1) Arrival-times-next record

A record with ARRIVAL TIMES NEXT starting in column 1 signals the start of the ARRIVAL TIME records. Each earthquake consists of four types of records: SUMMARY ('/' or '\' in column 83), ARRIVAL TIME, COMMENT ('C*' in columns 1-2) and INSTRUCTION. If any SUMMARY records are present, the first record of the

event must be the primary SUMMARY record ('/' in column 83) and this record provides the starting location for the event unless the IGNORE SUMMARY records is in effect (see 2.2.3.14 and 2.2.12). Each event must end with a series of one or more INSTRUCTION records. A maximum of NPA (see 1.3) records may be associated with each event.

- 2.2.6.2) Arrival-time-record format

For each seismograph station recording the earthquake, an ARRIVAL TIME record is typed as follows. A maximum of 256 phases, counting P and S phases, may be used for each earthquake.

Item	Column Numbers		Format
Station code	1	4	A4
Alphanumeric symbol describing P-phase arrival (for example, I or E)		5	A1
P-Phase descriptor		6	A1
P = P arrival read on vertical component N = P arrival read on North-South component E = P arrival read on East-West component If N or E is used, then neither the coda duration nor the maximum amplitude will be used and the first motion direction will not be plotted. The extended 5-character station code is formed from the station code in columns 1-4 (shifted to the right) plus the phase descriptor. If the phase descriptor is not n or e, then z is assumed. This extended name must agree with the extended name in the station list (see 2.2.5.2).			

First-motion direction of P arrival		7	A1
c, C, u, or U	Compression		

d, D	Dilatation			
+	Questionable compression			
-	Poor dilatation			
z, Z	Nodal, and not clearly up or down			
n, N	Noisy			
. or Blank	Not readable			
P-weight-code		8		F1.0
0 or blank	Full weight			
1	Partial weight			
2	Partial weight			
3	Partial weight			
4, 5, 6, 7, 8	No weight			
9	Use S-P interval (see 2.2.9)			
If the P phase is a secondary arrival refracted along the bottom of the ith layer, type the value of I here. If event is in the $(i + 1)$th layer, direct wave calculation is made. If the event is deeper than the $(i + 1)$th layer or the distance is too short for this refraction to be possible, then the computed weight is reset to zero. This option only operates with computed layer models with constant velocity (see 2.2.2.1.a).			9	i1
Year, month, day, hour, minute (e.g. 8912312359)		10	19	i10
Seconds of P arrival. If left blank, the assigned weight-code will be set to 8 both during this run and on the ARCHIVE ARRIVAL TIME record.		20	24	F5.2
Seconds of S arrival		32	36	F5.2

S remark (analogous to columns 7-9, e.g. iSN) (Not used by HYPOELLIPSE.)	37	39	A3
S-weight-code		40	F1.0
Maximum peak-to-peak amplitude. Values from .001 to 9,999 are entered as positive. Negative entries are multiplied by -10,000 to allow for values of 10,000 to 9,990,000. Units depend on calibration data (see Chapter 4).	44	47	F4.0
Period of maximum amplitude in hundredths of s. If left blank, 0.1 will be used.	48	50	F3.2
Siemens gain state: 0 = high; 1 = low (gain times 1/4)		61	i1
A1VCO gain-range state. 0 = high; 1 = gain times 1/10; 2 = gain times 1/500.		62	i1
Any remark	63	64	A2
Time correction (s)	66	70	F5.2
F-P time interval (s), for FMAG calculation. In USGS practice, one measures the time between the first P arrival and the point where the peak-to-peak amplitude of the signal drops below 1 cm on a Teledyne Geotech Develocorder film viewer (X 20 magnification). If the F-P time is less than 1.25 times the S-P time, then the FMAG is not calculated.	71	75	F5.0
Polarity source code		105	A1
P-arrival source code		106	A1
S-arrival source code		107	A1
Amplitude source code		108	A1
Coda-duration source code		109	A1

- See 4.2.2.2 for a listing of source codes used in Alaska.

- 2.2.6.3) Instruction record

After each set of ARRIVAL TIME records for a particular earthquake, at least one INSTRUCTION record follows.

Item	Column Nos.		Format
MORE Indicator for another INSTRUCTION record following this one. Leave blank if no additional INSTRUCTION records follow. Type MORE if another one follows. The earthquake will be processed once for each INSTRUCTION record.	1	4	A4
Processing Status		9	A1
Event Type. See 2.4.1 for definition of Processing Status and Event type. If a SUMMARY record does not precede an event, then the Processing Status and Event Type from the INSTRUCTION record are placed in columns 74 and 92 of the SUMMARY record generated when HYPOELLIPSE is run. If the event is in Archive Format, and is therefore already preceded by a SUMMARY record, then the event type and processing status on the INSTRUCTION record are ignored.		10	A1
S-data indicator. 0 if S data is not to be used. 1 for use of S data in solution. TEST(38) must be set to 0 for S-data indicator to be used (see 2.2.4).		18	i1
Fixed location indicator		19	i1
0 implies nothing fixed. 1 implies depth fixed at trial depth. 7 implies hypocenter fixed but origin time free. 8 implies origin time fixed at trial origin time. 9 implies location fixed at trial latitude, longitude, and depth. If origin time is entered on this record (cols. 74-80), or on a SUMMARY record, then origin time will also be fixed (see 2.2.12). If event type is T, R, or N on SUMMARY RECORD, fixed location indicator is ignored (see 2.4.1).			

Trial depth	20	24	F5.2
Trial latitude (Degrees)	41	42	F2.0
N or blank for North, S for South		43	A1
Trial latitude (Minutes)	44	48	F5.2
Trial longitude (Degrees)	54	56	F3.0
W or blank for West and E for East		57	A1
Trial longitude (Minutes)	58	62	F5.2
USGS "CUSP ID" (not used by HYPOELLIPSE)	63	73	A11
Trial origin time (Minutes)	74	75	F2.0
Trial origin time (Seconds)	76	80	F5.2
Sequence Number - will be transferred to columns 94-98 of SUMMARY record.	92	96	A5

- 2.2.6.4) Comment records

Any phase record with C* in columns 1-2 will be printed out during program execution but otherwise will be ignored. There is no limit to the number of COMMENT records per event, except that they count along with SUMMARY records, ARRIVAL TIME records, and the INSTRUCTION record toward the maximum number of records allowed per event - currently set at 256. In this way a comment can be made, for example:

C* Station XYZ may have cross-feed

    or

C* these readings may be from two earthquakes.

2.2.6.5) Jump records

If a record with 'JUMP FILENAME' beginning in column 1 is encountered then input is transferred to file 'FILENAME'. When an end-of-file is reached on the subsidiary input file, input resumes from the original file.

- *2.2.7 Station parameter changes during run (see 2.2.5.2 and 2.2.5.3)*

The station list record file may be set up so that station parameter changes will automatically be made as during a single batch run of a set of earthquakes. Each

STATION record has an expiration date and time. If left blank the year is set to 1999. But if, for example, the station calibration changed on 760120 at 1432 from 5.1 to 8.3, then two STATION records would be included in the file. The first would have 5.1 for calibration and an expiration of 7601201432. The second, which must directly follow the first, would be identical except 8.3 would replace 5.1 and the expiration date and time would be updated. As many STATION records as required can be grouped together like this. The expiration date of each station is checked against the current event time before each event is processed.

CAUTION: In order to use this system of automatic updating of station parameters, the earthquake data set must be run in chronological order. All updates for a particular station must also be in chronological order. Note that if the events are rerun, as described in section 2.2.11, then they will not be run in chronological order, so station parameter updating will not operate correctly and errors may result.

- *2.2.8 Change input items 2.2.1 through 2.2.5 during run*

Any or all of these items may be changed as follows:

- 2.2.8.1) Reset record

Type RESET starting in column 1. This record is placed following the last INSTRUCTION record of an event or set of events, and it switches the program to the input mode in which items 2.2.1 through 2.2.5 may be entered. All location parameters will remain in effect except those for which new 2.2.1-2.2.5 records are included. To switch back to reading PHASE records, terminate the 2.2.1-2.2.5 items with an ARRIVAL TIMES NEXT record.

- 2.2.8.2) Reset S record

Type RESET S starting in column 1. This is the same as RESET described above except that (1) a tabulation of average residuals will be printed for the set of events preceding the RESET S record, and (2) a tabulation will begin anew on the events that follow.

- 2.2.8.3) Standard test record

A record with STANDARD TEST starting in column 1 will reset input items 2.2.3 and 2.2.4 to default values. This record is placed after a RESET or RESET S record.

- *2.2.9 Use of S-P intervals*

If the same time base is not available for some stations, it is still possible to use the recorded S-P intervals in the hypocentral solution. To do this, set the weight-code assigned to the P arrival (column 8) to 9, and the weight-code assigned to the S arrival

(column 40) to that desired for the S-P interval. This will only work with velocity models that have the same ratio of P-wave to S-wave velocity in each layer.

▪ *2.2.10 How to add your own calibration curve - Format: CALIBRATION Integer*

In addition to the 8 system response tables stored with HYPOELLIPSE, the user may supply tables for up to nine additional seismic systems, corresponding to system numbers 9 through 17. To do this, place a record with CALIBRATION starting in column 1 and the number of additional system calibration tables to be added beginning in column 19 in free format. Each table consists of two records with the values of RSPA for n = 1,20 on the first and n = 21,40 on the second. The format is (20F4.2). The first two records correspond to system number 9, the second two to number 10, etc., up to the total number of tables to be added. See Chapter 4 for the definition of RSPA(n).

▪ *2.2.11 How to run the same data more than once*

A set of ARRIVAL TIME records may be run with a variety of velocity models, station lists, trial depths, or any other of the variable parameters defined in sections 2.2.1 through 2.2.5. First, place the ARRIVAL TIME records in a separate file (named PHDATA in the example below). Then set up the input file as in this example:

Items 2.2.1 through 2.2.5 as desired for 1st run

ARRIVAL TIMES NEXT
JUMP PHDATA
RESET

New items 2.2.1 through 2.2.5 as desired for second run

ARRIVAL TIMES NEXT
JUMP PHDATA

NOTE: HYPOELLIPSE always assumes that the earthquakes being processed are in chronological order when keeping the station parameters up-to-date. Therefore, if the events being rerun span any changes in the station parameters, the station file will have to be included again prior to rerunning the data.

▪ *2.2.12 Summary of first trial-location specifications*

For each parameter, the sources are given in order of decreasing priority.

LATITUDE AND LONGITUDE

INSTRUCTION record, if specified (columns 41-44 contain some non-blank characters), else

SUMMARY* record, if specified (columns 17-20 contain some non-blank characters) - (See 2.2.3.14 to ignore SUMMARY records), else

TEST(3) and (4) values, if both not equal zero, else

Inversion* of up to the first 10 P-arrival times.

DEPTH

If Global Option is in effect, then use multiple starting depths as described in 2.2.3.11.

Use INSTRUCTION record, if depth is specified (columns 21-24 contain some non-blank characters), else

SUMMARY* record, if specified (columns 33-36 contain some non-blank characters) - (See 2.2.3.14 to ignore SUMMARY records), else

Trial depth specified in SUBROUTINE USEDLY if the SELECT DELAY code is not zero and USEDLY sets a depth not equal to 99999. (See 2.2.3.6), else

TEST(5), if not equal -99.0, else

Inversion* of up to the first 10 P-arrival times, rounded to nearest 5 km and not less than 15 km or greater than TEST(36).

ORIGIN TIME

Computed from distribution of S vs P if TEST(49) equals -1 or -2 and the number of pairs of S and P times is greater than 2.

INSTRUCTION record, if specified (columns 74-77 contain some non-blank characters), else

SUMMARY* record, if specified (columns 11-14 contain some non-blank characters) - (See 2.2.3.14 to ignore SUMMARY records), else

Computed from distribution of S vs P if TEST(49) equals 1 or 2 and the number of pairs of S and P times is greater than 2.

Define $TO(i) = TP(i) - (TS(i) - TP(i))/(TEST(1) - 1.0)$ where

$TP(i)$ is the P-arrival time at the ith station,
$TS(i)$ is the S-arrival time at the ith station,
TEST(1) is the Vp/Vs ratio

Use the average value of $TO(i)$ if at least one station has both P- and S- arrivals, else

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Inversion of up to the first 10 P-arrival times based on a halfspace with velocity = TEST(48).

NOTE: If TEST(38) is negative, then the origin time will be fixed at the average value of TO(i), unless TEST(49) is negative, in which case it will be fixed at the value determined by the Wadati plot (extrapolation of the (TS - TP) vs TP curve to the point where (TS - TP) equals zero).

*NOTE: Starting parameters will not be taken from the SUMMARY record if the IGNORE SUMMARY RECORD is in effect (See 2.2.3.14).

- *2.2.13 Run data with random errors added*

In order to study the effectiveness of this inversion program for varying station distributions or earthquake distributions, the following method may be used:

a) Generate a "fake" set of perfect phase data for the desired earthquake distribution. This can be done by setting up a group of ARRIVAL TIME records with the stations of interest and including arbitrary P- and S-phase data for each station. Then use a series of INSTRUCTION records, each with a fixed location indicator and one of the desired test earthquake locations (See 2.2.6.3). Run this data with SUMMARY OPTION 4 in order to generate the "fake" set of arrival time data. If these data were fed back into the program, the result should be the desired test earthquake locations, each with a zero RMS residual.

b) In order to have random errors added to each arrival time each time the "fake" data are relocated, type a control record with SCATTER starting in column 1, P-standard error starting in column 20 (F5.2), and S-standard error starting in column 32 (F5.2). Note that this format is fixed. These should be the standard errors for readings with a weight-code of zero. For readings with weight-codes of 1, 2, and 3, larger deviations will be added, based on the WEIGHT parameters (see 2.2.3.13). Place this record directly before the first ARRIVAL TIME record of the fake data set. If an archive phase file is being generated, the arrival times will reflect the added random errors. Each time this job is run a new series of random numbers will be generated because the random number seed is initialized by the time, month, and year of the run.

If the velocity model is also changed, then one can also simulate the systematic errors introduced by not knowing the true earth structure.

Note that an archive file written when SCATTER is in effect will have all of the original arrival times perturbed by random errors.

c) To simulate a non-Gaussian distribution, add a record with NONGAUS starting in column 1, fraction of readings with larger error starting in column 20 (f5.2), and factor by which to increase P & S standard errors starting in column 32 (f5.2). for example, to randomly increase P & S standard errors by a factor of 5 10% of the time, use:

NONGAUS 0.1 5.0

■ *2.2.14 Define a MASTER event for a random location study*

This option may be used to test the hypothesis that all of the events in a set of locations are located at the same hypocenter, and are only apparently shifted due to random reading errors and variations in which phases were read for each event. Set up a "perfect" event (an event with zero RMS residual) located at the hypothesized hypocenter. Place this as the first of a set of earthquakes and precede it with a record that has MASTER starting in column 1. Specify the reading errors with a SCATTER record next (see 2.2.13). All events following the first will have their minutes and seconds of P and S replaced with the "master" values. Due to the SCATTER option, the computed locations will vary randomly. The spatial distribution of the resulting random distribution and the summary statistics at the end of the run can be compared with the actual data set to test the hypothesis.

■ *2.2.15 How to generate an ARCHIVE-PHASE FILE*

HYPOELLIPSE can be used in a mode that utilizes and generates data in a data base that combines the raw data measurements of the PHASE records, the SUMMARY record, and certain derived parameters for each station such as the distance, the azimuth, and the angle of incidence (see Data Base Organization table below). To set up HYPOELLIPSE to generate this file, named the ARCHIVE-PHASE FILE, set the SUMMARY OPTION code equal to 2 or 3 (see 2.2.3.2). The file is generated by the following steps:

Write out SUMMARY record(s).

Case 1. The input event included either zero or one SUMMARY records. (Note that the first (primary) summary record will have a "/" in column 83. Any additional summary records will have a "\" in column 83.)

Case 1a. A new earthquake solution was generated. Then: Write a SUMMARY record for the new solution and discard the previous SUMMARY record, if there was one.

Case 1b. A new solution was not generated. This could happen, for example, if all of the arrivals are weighted out. Then: Write out a FAKE SUMMARY record followed by the SUMMARY record that was previously associated with the event, if there was one.

Case 2. The input event included two or more SUMMARY records.

Case 2a. A new earthquake solution was generated. Then: Write out the new SUMMARY record followed by all but the first of the SUMMARY records previously associated with the event.

Case 2b. A new solution was not generated. Then: Write out a FAKE SUMMARY record followed by all of the SUMMARY records previously associated with the event. A "FAKE" summary record is just a placeholder, with the earthquake location and depth fields left blank.

For each station, write out an augmented PHASE record with original phase data and computed data.

Write out the original INSTRUCTION record.

The generation of archive-phase files is not compatible with option of running events with more than one INSTRUCTION record (see 2.2.6.3, 'MORE').

Data Base Organization

Organization of the old and new data base structures. Raw and derived data that were previously stored in three files are now combined into a single ARCHIVE-PHASE FILE	
OLD DATA BASE	NEW DATA BASE
PHASE records with raw data measurements in one file.	One archive-phase file with raw and derived information for each station as well as the derived earthquake solution parameters.
SUMMARY records with: derived earthquake solution parameters, such as location depth, origin time and magnitude in another file.	
Printed listings with: derived station information, such as distance, azimuth, angle of incidence, and magnitude.	

The ARCHIVE-PHASE FILE may be used as a HYPOELLIPSE input phase file. In that case, the starting location, depth, and origin time will be taken from the first SUMMARY record associated with the event unless overridden by a location, depth, or origin time on the INSTRUCTION record (section 2.2.6.3). The format specification for reading an ARCHIVE ARRIVAL TIME record is as follows:

Item	Col. Nos.		Format
Station code	1	4	A4

	From	To	Format
Any two alphanumeric symbols to describe P phases. See 2.2.6.2)	5	6	A2
First motion direction of P arrival		7	A1

c, C, u, or U	Compression
d, D	Dilatation
+	Questionable compression
-	Questionable dilatation
n, N	Noisy
.or Blank	Not readable
z, Z	Nodal, and not clearly up or down

P-weight-code			8	F1.0

0 or blank	Full weight
1	Partial weight
2	Partial weight
3	Partial weight
4, 5, 6, 7, 8	No weight
9	Use S-P interval (see 2.2.9)

If the P phase is a secondary arrival refracted along the bottom of the Ith layer, type the value of I here. If event is in the (I + 1)th layer, a direct wave calculation will be made. Below that, the weight is reset to zero.		9	i1
Year, month, day, hour, minute (e.g. 9812312358)	10	19	i10
Seconds of P arrival	20	24	F5.2
Distance (km)*	25	28	F4.1
AZM - Azimuth from epicenter to station (degrees)*	29	31	F3.0
Seconds of S arrival	32	36	F5.2

S remark	37	39	A3
S-weight-code		40	F1.0
AIN - Angle of ray leaving hypocenter (degrees)*	41	43	F3.0
Maximum peak-to-peak amplitude. Values from .001 to 9,999 are entered as positive. Negative entries are multiplied by -10,000 to allow for values of 10,000 to 9,990,000.	44	47	F4.0
Period of maximum amplitude (s). If left blank, the standard period as specified in the station list will be used	48	50	F3.2
P travel-time computed*	51	54	F4.2
P standard error*	55	57	F3.2
D, B, M, J, X, R, G, or * weight-code (See 2.3.7 for definition)*		58	A1
Instrument Period (S=short, L=long, B=broad)		59	A1
Instrument Gain (H=high, L=low)		60	A1
Siemens gain state: 0 = high; 1 = low (gain times 1/4)		61	i1
A1VCO gain range state. 0 = high; 1 = gain times 1/10; 2 = gain times 1/500		62	i1
Remark (Recorder location in column 63, e.g. F=Fairbanks)	63	64	A2
Corrected first-motion symbol		65	A1
Time correction (s)	66	70	F5.2
F-P time interval (s) for FMAG	71	75	F5.0
P:RES - Residual of P arrival (s)*	76	80	F5.2
S standard error*	81	83	F3.2
D, B, M, J, X, R, G, or "*" weight-code*		84	A1
S:RES - Residual of S arrival (s)*	85	89	F5.2

P delay*	90	92	F3.1
S delay*	93	95	F3.1
P elevation delay*	96	98	F3.1
System response code*	99	100	i2
XMAG*	101	102	F2.1
FMAG*	103	104	F2.1
Polarity source code**		105	A1
P-arrival source code**		106	A1
S-arrival source code**		107	A1
Amplitude source code**		108	A1
Coda-duration source code**		109	A1
Number of satellite hops (NHOP) in telemetry path, each producing a delay of 0.27 s. (If the P-arrival and S arrival sources are not the same, then NHOP is set according to the P-arrival source.) *		110	i1

* These items are added to the original ARRIVAL TIME record, but are not used in subsequent runs of HYPOELLIPSE

** See 4.2.2.2 for a listing of source codes.

Use of Polarity Source Code by HYPOELLIPSE:

STATION records have two fields for keeping track of station polarity (see 2.2.5), the Polarity-Reversal-Indicator in column 34 and the Tape-Polarity-Reversal-Indicator in column 48, and these two indicators do not always agree. The Polarity-Reversal-Indicator is used in correcting the observed first motion unless the polarity source code is S, in which case the Tape-Polarity-Reversal-Indicator is used.

▪ *2.2.16 How to close current ARCHIVE-PHASE FILE and open a new one*

In some situations it is desirable to close the archive-phase file specified when the program was started and to open a new file with a different name. To do this, use a record with ARC in columns 1-3 and the new file name in columns 19-68. The ARC record must either be included with the initial input data or follow a RESET record. The

following example illustrates a run in which P1.ARC corresponds to P1.PHA and P2.ARC corresponds to P2.PHA.

➤ {Items 2.2.1 through 2.2.5}

➤ ARC P1.ARC
    ARRIVAL TIMES NEXT
    JUMP P1.PHA
    RESET
    ARC P2.ARC
    ARRIVAL TIMES NEXT
    JUMP P2.PHA

▪ *2.2.17 Use of magnitudes not determined by HYPOELLIPSE*

For some earthquakes it is desirable to use a magnitude calculated by another organization, and to enter this magnitude in columns 37-38 of the SUMMARY record as the preferred magnitude. In this situation MAGTYP in column 80 is also set to some code other than F, X, or A. For example, in Alaska we use the following codes:

Mag. Type	Source
B	PDE mb
C	Canadian M_L
G	UAGI M_L
H	Helicorder (approximate M_L)
P	Palmer M_L
L	Lamont-Doherty Earth Observatory
O	Other
S	PDE M_S
W	Moment magnitude (Mw)

When earthquakes are being rerun, if the SUMMARY record precedes the phase data (See 2.2.15) and has MAGTYP not equal to F, X, or A, then the preferred magnitude and MAGTYP on the newly generated SUMMARY record will not be changed. Thus, the preferred magnitude is preserved through repeated runs of HYPOELLIPSE.

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➤ *2.3 Printed output*

The line-printer outputs of HYPOELLIPSE are generally self-explanatory. The following explanations may be helpful for first-time users.

▪ *2.3.1 List of stations available (each station uses two lines in the printout)*

Heading	Explanation
P THK	Preferred variable layer thickness. Either 1 or 2.
VAR LAYER THICKNESS 1 and 2	Two thicknesses may be specified for the variable layer.
P MOD	Number of velocity model to be used with this station.
P DLY	Preferred delay model 1 through 5.
PDLY1, SDLY1	Model 1 time delays for P and S arrivals. Followed by delays for models 2 through 5.
SYS	System response code. See 2.2.5 on station list for code number assignments.
CALR	Standard calibration for XMAG
XMGC	Amplitude magnitude correction
FMWT	Weight for F-P magnitudes
FMGC	F-P magnitude correction. Multiplies observed F-P interval.
WT P	Replace P-weight-code of 0, 1, 2, or 3 with this. Ignored if equal to 10.
WT S	Replace S-weight-code of 0, 1, 2, or 3 with this. Ignored if equal to 10.
POL	Two codes are printed, the first for Develocorder polarity and the second for tape polarity. If 1, then reverse observed polarity before plotting on focal-sphere. If > 1, plot as a question mark.
STAWT	The reading weight is multiplied by STAWT.

TLDLY	Correction to be added to the observed time.
	Used for satellite delays for USGS Alaska data.
YRMODY	Year, month, and day of expiration of time-dependent station parameters.
HRMN	Hour and minute of expiration of these parameters

- *2.3.2 Program specifications*

The TEST variables and abbreviated definitions are printed out so that each run is well documented. The station list and the velocity models are also printed out.

- *2.3.3 Vp/Vs ratio*

If the Vp/Vs-value is in effect (see TEST(49), section 2.2.4) the computed Vp/Vs ratios are printed out. See Chapter 5 for an explanation of the calculations.

- *2.3.4 Iteration output*

It is recommended that PRINTER 1 be used. One line will then be printed per iteration as follows:

Heading	Explanation
I	Iteration step. If a particular step is repeated, I is not incremented.
LAT	Minutes of latitude
LON	Minutes of longitude
DEPTH	In kilometers
*	If depth is constrained.
RMS	Root-mean-square travel-time residual (s). See equation below
NO	Number of P, S and S-P readings used
PRMS	RMS predicted for after the next step. See 4.4 for discussion.
DAMP	Value of damping constant in use. See 4.

EIGENVALUES	The three eigenvalues of the spatial normal equations.
ADJUSTMENTS COMPUTED DLAT, DLON, DZ	The adjustments in the principal directions are converted into changes in latitude, longitude, and depth.
ADJUSTMENTS TAKEN DLAT, DLON, DZ	This adjustment will be taken to reach the next iterative location. The limits imposed by the TEST variables have been applied.

Equation for root-mean-square travel-time residual (RMS). For i phases, $i = 1, N$, R_i is the observed minus computed time of the ith phase. W_i is the computed weight of the ith phase.

$$RMS = \left[\frac{\sum_1^n W_i R_i^2}{\sum_1^N W_i} \right]^{1/2}$$

- *2.3.5 Quality*

- 2.3.5.1 Based on error estimates

This quality is based on the values of SEH (the horizontal 68% confidence limit in the least well-constrained direction) and SEZ (the 68% confidence limit for depth). See Chapter 3 for further explanation of SEH and SEZ. Note that the following limits are modified from those used previous to April 1984 to reflect revised definitions of ERH and SEZ.

Quality	Larger of SEH and SEZ
A	≤ 1.34
B	≤ 2.67
C	≤ 5.35
D	> 5.35

- 2.3.5.2 Quality based on many parameters

SQD-HYPO71 Quality

S is the solution quality as defined in HYPO 71:

S	RMS	SEH**	SEZ**
A	< 0.15	≤ 1.0	≤ 2.0
B	< 0.30	≤ 2.5	≤ 5.0
C	< 0.50	≤ 5.0	
D	Others		

- SEH is the horizontal 68% confidence limit in the least-well-constrained direction.

** SEZ is 68% confidence limit for depth.

The letter "Q" is used just as a spacer in the string "SQD".

D is the station distribution quality as defined in HYPO71:

D	No.	GAP	DMIN
A	≥ 6	≤ 90	$\leq$ DEPTH or 5 km
B	≥ 6	≤ 135	$\leq 2*$DEPTH or 10 km
C	≥ 6	≤ 180	≤ 50 km
D	Others		

DMIN is the distance to the nearest station.

- *2.3.6 Final summary output lines*

Heading	Explanation
SE OF ORIG	Standard deviation of origin time.
# OF ITERATIONS	Total number of iterations
DMAX	Distance weighting maximum distance.
SEQUENCE NUMBER	Sequence number from columns 94-98 of SUMMARY record preceding this event.
EVENT TYPE	Column 92 of SUMMARY record (see 2.4.1).
PROCESSING STATUS	Column 74 of SUMMARY record (see 2.4.1).
DMAX	Final value of XFAR, based on TEST(12) and TEST(46).
DATE	If solution based only on S-P data, an * will follow date.
ORIGIN	Hour Minute Second
LAT	Degrees and minutes
LON	Degrees and minutes
DEPTH	Kilometers
MAG	Preferred magnitude. Also entered on SUMMARY record in columns 37-38. See 2.2.3.3, 2.2.17, and 2.4.1.
NO	Number of P, S, and S-P readings used in the solution.
D1	Distance to the closest station used in the solution (km).
GAP	Largest azimuthal separation in degrees between stations as seen from the epicenter.
D	Number of delay-model used (1 to 5).
RMS	If the residuals are R_i and the weights are W_i, i = 1, N, then equation for RMS is as given below.
AVWT	Weights are normalized so that their sum equals NO by dividing each weight by the average weight, AVWT.

SEH	Horizontal 68% confidence-limit for the least-well-constrained direction.
SEZ	68% confidence-limit for depth.
Q - HYPO71	Average of S and D qualities defined in 2.3.5.2. Rounded to lower quality when necessary.
SQD	S and D qualities defined in 2.3.5.2.
ADJ	Length (km) of final adjustment of hypocenter.
I	S-data indicator. 0 - S not used 1 - S is used
N	Fixed location indicator. 0 - nothing fixed, 1 - depth fixed at trial depth, 8 - origin time fixed at trial origin time, 9 - location fixed at trial hypocenter
NR	Total number of P, S, and S-P readings
AVR	Average-weighted residual.
AAR	Average of the absolute value of the weighted residuals.
NM	Number of stations at which amplitude magnitude (XMAG) was calculated.
AVXM	Average XMAG.
MDXM	Median XMAG.
SDXM	Standard deviation of XMAG's calculated, with respect to AVXM.
NF	Number of stations at which F-P magnitude (FMAG) was calculated.
AVFM	Average FMAG.
MDFM	Median FMAG
SDFM	Standard deviation of FMAG's calculated, with respect to AVFM.
VPVS	Computer slope of Tp vs Ts.

Equation for root-mean-square residual:

$$RMS = \left[\frac{\sum_1^n W_i R_i^2}{\sum_1^N W_i} \right]^{1/2}$$

- *2.3.7 Detailed station output: TRAVEL TIMES AND DELAYS:*

Heading	Explanation.
STN	Station code.
C	Component. Z - vertical. N - north-south horizontal. E - east-west horizontal.
PHA	Phase. Blank for P-phase. S for S-phase. SMP for S minus P interval.
REMK	Phase remark (columns 5-8 of PHASE record).
P	First-motion polarity, corrected as per station history.
PSEC	Seconds of P-arrival as typed on ARRIVAL TIME record.
SSEC	Seconds of S-arrival as typed on ARRIVAL TIME record.
RESID	Residual (s).

	If a character follows the residual the meaning is: D = Weight reduced to zero by distance weighting. B = Weight reduced to zero by boxcar weighting. M = Weight reduced to zero by truncation weighting. J = Residual is greater than 3 standard deviations from the mean. Used with Jeffrey's weighting. X = Weight reduced to zero during critical station run (see TEST(44)). R = Computed weight less than 0.0005, so set to zero. G = Beyond distance weighting cutoff but included in order to reduce gap (See TEST(46)). * Large residual flagged by RESIDUAL OPTION (See 2.2.3.12).
STD-ER	Standard error(s) used for this arrival in hypocentral solution. The weight assigned to each phase is proportional to the inverse square of the standard error of the phase.
DIST	Epicentral distance of station (km).
AZM	Azimuth of station from epicenter (degree).
AIN	Angle of ray leaving hypocenter measured with respect to downward vertical (degree).
TC	Station clock correction (s) from ARRIVAL TIME record. Added to observed arrival time.
C	Velocity model used for this travel time.
VTHK	Thickness of the variable layer in km for the velocity model used.
TTOB	Travel time observed (s).
TTCAL	Travel time calculated (s).
DELAY	Station delay (s) for model preferred by closest station.
EDLY	Elevation delay (s).
RMK	Remark from columns 63-64 of PHASE record.
STN	Station code.
SOURCES	Phase data sources followed by number of satellite hops, columns 105-110 of original PHASE record.

MAGNITUDE DATA:	
SOURCE	Amplitude source code from column 108 of ARRIVAL TIME record.
SYS	System response used in computing magnitude.
C10	XMAG calibration constant for USGS magnitude subroutine; For UAGI magnitude subroutine, system magnification in counts per 10^{-6} mm at the period (PER) of wave. Set to -1.0 if calibration data is not available.
AMX	Maximum amplitude from input data, peak-to-peak (mm).
GR	A1VC0 gain range state, 0 = normal; 1 = gain times 1/10; 2 = gain times 1/500.
INK	Siemens playback gain, 0 = high; 1 = low (gain times1/4).
AMF	Maximum amplitude (mm), corrected for gain state and Siemens playback record.
PER	Period (s) of wave where maximum amplitude was read. If PER is not given on ARRIVAL TIME record, then standard period from station archive is used. The default is 0.1s.
UNIT/MM	Station gain at period PER.
GND MOT m	Ground motion (microns), peak-to-peak.
XMGC	XMAG station correction.
XMAG	Amplitude magnitude. An 'e' (for Excluded) follows if XMAGWT = 0; if not, an '*' follows XMAG if XMAG - AVXM > 0.5.
FMP	F-P time interval (s).
FMAG	Coda magnitude. An S follows if the coda was too short with respect to the S-P time for a coda magnitude to be computed; if not, an 'e' (for Excluded) follows the FMAG if FMAGWT = 0; if not, an * follows FMAG if FMAG - AVFM > 0.5.

- *2.3.8 Auxiliary RMS sphere output*

At times there may be a concern that the final iterative earthquake location is not the best one possible. If TEST(6) .NE. 0.0, (see 2.2.4) then the RMS residual is calculated at 14 points on a sphere of radius = TEST(6) centered on the final hypocenter. If the hypocenter is at a minimum of RMS in space, then all the points on the sphere will have larger RMS values than the center point. The DRMS is the RMS on the sphere minus the RMS at the center and will be positive for good locations.

The average DRMS values at the ends of seven diagonals through the sphere are calculated. These are printed in order of poorest to greatest location control and are specified by their down-dip azimuths. If TEST(6) is negative and if a point on the sphere has lower RMS than the center of the sphere, iteration will resume at that point in order to improve the solution. This is allowed only once per earthquake solution to prevent an infinite loop condition from arising.

A tabulation is printed listing the number of readings used, the RMS at the center, the minimum DRMS, the average DRMS, and a quality based upon these values as follows:

Q	NUMBER	RMS	MIN DRMS	AVE DRMS
A	> 6	≤ 0.2	≥ 0.3	
B	≥ 5	≤ 0.4	≥ 0.15	
C	≥ 4	≤ 0.4		≥ 0.5
D	Others			

- *2.3.9 Focal mechanism plot*

If the number of first motions is greater than or equal TEST(7) a focal-mechanism plot will be made on the printer. The diagram is an equal-area projection of the lower hemisphere of the radiation field. The symbol printed is as follows:

+	1 or more +'s
C	1 compression
B	2 compressions
A	3 or more compressions
X	Any combination of compressions and dilatations
-	1 or more -'s

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D	1 dilatation
E	2 dilatations
F	3 or more dilatations
?	Indicates that although a first motion was reported,
	the station polarity is uncertain.

A +, -, or ? is printed only if a compression or a dilatation does not occupy the position.

If TEST(7) < 0, a second plot will be made showing station codes on the focal sphere.

Use TEST(45) = .1379 for 8.5-inch paper and TEST(45) = .10106 for 11-inch paper.

▪ *2.3.10 Final Tabulation*

At the end of each run of a set of earthquakes, a table is printed which gives the number of earthquakes within each quality specification. There is also a table which shows for each station the number of times the station was used (N), the average weight (WT), the weighted average residual (AVE), and the standard deviation of the residuals about their mean (SD). The TABULATION option (see 2.2.3.4) controls the quality of the events included in this table.

For P and S arrivals there are sets of two columns in the table. The first bases the weight for the ith residual from the kth event only on the final weight prior to normalization, WT_{ik}, used in locating the kth event. The second also includes an event-weighting factor, F, based upon the number of arrivals and their weights used in locating each event. For the kth event:

F_k = SUMWT$_k$ * (NRWT - 4)/NRWT$_k$, for NRWT$_k$ > 4

F_k = 0.0, for NRWT$_k \leq 4$

where NRWT$_k$ is the number of readings used in locating the kth event, and SUMWTk is the sum of the weights (WT_{ik}) of the arrivals of the kth event. Inclusion of the factor F in the weights used to compute the average station residual will bring the average residual into closer agreement with the modification in station correction that would be obtained from a joint inversion of all of the events for both location and station correction. Pavlis and Hokanson (1985) suggested using SUMWT$_k$ for this purpose. The addition of the degree of freedom term, (NRWT - 4)/NRWT should further improve the technique, in that the residual pattern for an event with few degrees of freedom will be unlikely to reflect the true station residuals. For data sets consisting of a large number of events, iterative modification of the station corrections using this table of averages

and then relocating the earthquakes will give approximately the same results as a joint inversion for both the locations and the station corrections (Pavlis and Booker, 1983; Pavlis and Hokanson, 1985).

If a station is given zero weight on its STATION record (see 2.2.5), it will be included in the tabulation even though it has not been used in any of the solutions. In this case the station code will be proceeded by a 'W'. If a station is assigned a P-weight-code replacement of 4-8 on the TIME-DEPENDENT STATION parameter record (see 2.2.5.3), then the summary will include average P-residual information even though the P arrivals were not used, and the P-residual standard deviation will be followed by a 'P'. The S-residual standard deviation will be followed by an 'S' in analogous situations. In either this case or the case where the station weight is zero, the weight used in the tabulation is based on the P-weight-code on the ARRIVAL TIME record (See 2.2.6).

WARNING: The station weight and the P- and S-weight-replacement codes are time-dependent parameters specified in the station list. The final tabulation assumes, however, that the station weight for a given station was either zero or non-zero during the entire run, and similarly, that the weight-code replacements either were or were not within the range 4-8 during the entire run. If these assumptions are not correct, the tabulation will be in error.

➤ *2.4 Summary record output*

The SUMMARY OPTION record described in 2.2.3.2 controls the SUMMARY record output. The STATION records are generated in the same format as the input STATION records. The other formats are given below.

▪ *2.4.l Summary record*

To save space no decimal points are used. Use the FORTRAN format for reading the summary record given below.

Item	Column Nos.		Format for Reading
Origin Time:			
KDATE - year, month, day (e.g. 19981231)	1	8	i8
KHRMN - hour, minute (e.g. 2358)	9	12	i4
KSEC - (seconds)	13	16	F4.2
LAT (degrees)	17	18	i2

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N or S		19	A1
LAT (minutes)	20	23	F4.2
LON (degrees)	24	26	i3
E or W		27	A1
LON (minutes)	28	31	F4.2
DEPTH (km) [If negative, reset to -00]	32	36	F5.2
PREFERRED MAGNITUDE	37	38	F2.1
NO - Number of P, S, and S-P readings used in the solution	39	41	i3
GAP - Largest azimuthal separation in degrees between stations as seen from the epicenter (deg.)	42	44	i3
D1 - Distance to closest station used in solution (km)	45	47	F3.0
RMS (s)	48	51	F4.2
Azimuth of axis 1 of error ellipsoid (deg)	52	54	i3
Dip of axis 1 (deg)	55	56	i2
SE - length of ellipsoid semi-axis 1 (km)	57	60	F4.2
Azimuth of axis 2 of error ellipsoid (deg)	61	63	i3
Dip of axis 2 (deg)	64	65	i2
SE - length of ellipsoid semi-axis 2 (km)	66	69	F4.2
Average XMAG	70	71	F2.1
Average FMAG	72	73	F2.1
Processing state (not used by HYPOELLIPSE)		74	A1

* - More data available to be added
P - Preliminary, but location not finalized
F - Final location determine
G - National Earthquake Information Center (NEIC) solution
A - NEIC solution obtained from USGS/UAGI
N - Not of principal interest
I - Insufficient data to determine a hypocenter

SE - length of ellipsoid semi-axis 3 (km)	75	78	F4.2
Quality - either error-ellipsoid quality or HYPO quality depending upon QUALITY OPTION record. (See 2.2.3.4) [In reformatted NEIC data this column contains the depth quality indicator.]		79	A1
MAGTYP - F, X, A, or K to indicate which type of magnitude is entered in columns 37-38. (See 2.2.3.3 and 2.2.17)		80	A1
NSWT - Number of S-phase arrivals used in solution.	81	82	i2
/ or \ The primary SUMMARY record is always first and has a "/" in column 83. If an archive file has more than one SUMMARY record, the second and any subsequent records will have a "\" in column 83.		83	A1
First 4 characters of INSTRUCTION record	84	87	A4
Month earthquake was run	88	89	i2
Year earthquake was run	90	91	i2
Event type		92	A1

E or blank	local or regional earthquake	S	artificial source such as seismic line or shot
T	teleseism	O	other non-earthquake (e.g. sonic boom or lightning)

R	regional (poor coverage; use solution from another organization)	C	calibration signal	
N	nuclear explosion	A	volcano tectonic (VT)	
G	glacial event	B	volcano long-period (LP)	
Q	quarry or mine explosion	X	emergent, low frequency near volcano,	
F	false trigger	V	volcano tremor burst or eruption	
I	Augustine volcano shore-ice event	H	volcano VT-LP hybrid	
+	continuation of previous event			

For type T, R, or N, do not compute the hypocenter location, but instead compute the azimuth and apparent velocity across the network.

Once the event type has been placed on the SUMMARY record of an earthquake in archive format, it will be transferred to succeeding SUMMARY records generated by later runs of HYPOELLIPSE.

Fixed location indicator, from column 19 of INSTRUCTION record or imposed by SELECT DELAY option (2.2.3.6)		93	i1
Sequence number	94	98	A5
S-P time at closest station used in solution. Blank if either P or S is not used. Set to 9999 if S-P .GE. 100.	99	102	F4.2
ZUP - Computed with GLOBAL OPTION.	103	104	F2.0
ZDN - Computed with GLOBAL OPTION.	105	106	F2.0
Vp/Vs - Computed slope of Ts vs Tp. Only computed if TEST(49) is not equal 0.	107	110	F4.2
Number of readings weighted out due to Jeffrey's, truncation, or boxcar weighting.	111	112	i2
DEPTH (km) [Allowed to be negative]	113	117	F5.2

- *2.4.2 Phase records in input format with corrected arrival times*

This option will create a "perfect" set of data, which then may be used to check the HYPOELLIPSE program. For example, one might want to know how well the program would work on events in some particular region. Fixed solutions specifying this

epicentral region could be run with SUMMARY OPTION 5 and test earthquakes would be generated. The "perfect" data will be generated as follows:

Item	Column Nos.		Format for Reading
Station code	1	4	A4
KDATE	10	15	i6
KHRMN	16	19	i4
SPEC - P-arrival time	20	24	F5.2
SSEC - S-arrival time	32	36	F5.2